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MAN-MACHINE DESIGN CONSIDERATIONS IN SATELLITE DATA MANAGEMENT.(U)

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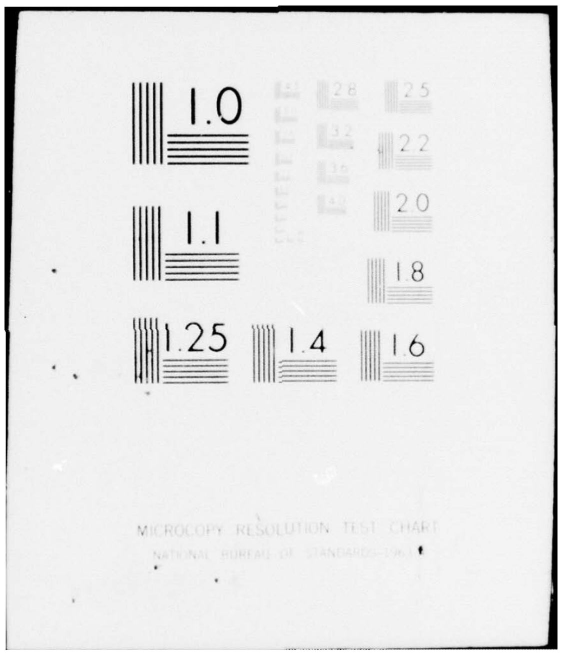
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MAN-MACHINE DESIGN CONSIDERATIONS IN SATELLITE DATA MANAGEMENT

BILLY M. CRAWFORD
DONALD A. TOPMILLER, PhD

AEROSPACE MEDICAL RESEARCH LABORATORY

GEORGE A. KUCK (PhD), MAJOR, USAF

SPACE AND MISSILE SYSTEMS ORGANIZATION
LOS ANGELES AIR FORCE STATION
LOS ANGELES, CALIFORNIA 90009

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AEROSPACE MEDICAL RESEARCH LABORATORY
AEROSPACE MEDICAL DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Charles Bates

CHARLES BATES, JR.
Chief
Human Engineering Division
Aerospace Medical Research Laboratory

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The report is divided into three sections: Section I is an introduction to human information processing theory with implications of the human information processing capacity and limitations for the Satellite Data Management (SDM) "User Pipe"; Section II incorporates two subsections dealing with man/computer relationships and computer decision aiding techniques; no attempt is made to specify specific design considerations for SDM--only implications can be inferred; Section III is an attempt to relate the first two general sections to some of the anticipated conceptual design issues for Satellite Data Management.

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PREFACE

This is the final report prepared by Systems Research Branch (AMRL/HEB), Human Engineering Division of the Aerospace Medical Research Laboratory, in coordination with, and in response, to agreements with SAMSO/YAPC Advanced Concepts Division. This report was prepared by Mr. Billy M. Crawford and Dr. Donald A. Topmiller with contributions by Dr. Robert G. Mills of AMRL/HEB and Major George Kuck, Space and Missile Systems Organization, Los Angeles Air Force Station, CA.

The source of the material included in this report stems from published Human Engineering literature, Engineering Psychology, Human Performance theory and Computer Science references. During the study phase pertinent IRAD programs at UNIVAC, Martin Denver, and the IBM Research Institute were surveyed.

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SECTION I

INTRODUCTION

A MODEL OF THE HUMAN COMPONENT

This Section is an introduction to human information processing theory with implications of the human information processing capacity and limitation for the Satellite Data Management "User Pipe."

In man-machine systems analysis the human component is frequently treated as an information system (Fig. 1). The human senses detect and encode energies from the physical environment. The human memory provides short- and long-term storage of the encoded information. The human information processing subsystems, supported by short- and long-term memory, act upon the sensory inputs to differentiate signal from noise, identify signal patterns, make decisions and select appropriate responses for transmitting information indicative of decisions made. The responses are executed via the human body, its limbs, eyes and/or speech mechanism.

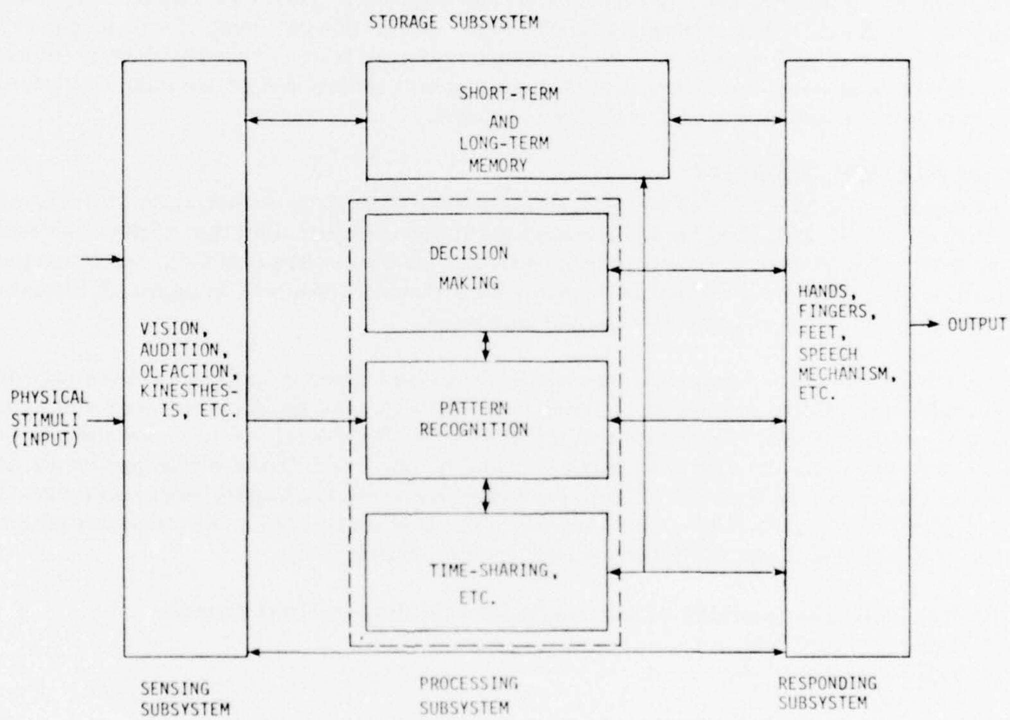

Figure 1. Human Information Processing Model

Two major parameters are critical to effective quantification of the human as an information processing system: (1) the amount of information he can transmit and (2) the transmission rate. If human information processing limits are not considered during man-machine system design, inefficient allocation of man-machine functions and operator information overload may result. Such considerations are especially important in designing systems that involve interaction between human operators and high speed digital computers in real time.

Efforts have been made to quantify human information capacities in terms of "bits"—the communication theory metric based on the number of two-choice discriminations required to specify a particular message from among all possible alternatives. (When the probabilities for alternative messages are the same, the information measure for a system in bits is equal to the logarithm to the base two of the number of alternative messages which can be transmitted.)

MEMORY STORAGE

The human information system is limited by the input-output stages rather than by the memory storage or central processing capabilities. Although it has been suggested that the human memory is virtually unlimited (limited access due to memory delays and "mental blocks" being the principal problem), Geyer and Johnson (1957) specify a storage capacity ranging from 10^8 to 10^{15} bits of information. However, the more practical considerations for man-machine system design are related to information input/output and memory access and stability over time.

SENSORY CHANNEL CAPACITY

Input capacities for the human information system are a function of the sensory mode and dimensions of the physical stimulus used. The *channel capacity* for vision is higher than that of the other senses. In comparison with the electro-optical scanners, man has an impressive ability to recognize patterns. Specifications for information capacities required by a machine designed to approach human visual pattern recognition and discrimination are not available.

Factors which contribute to determination of sensory channel capacity include: (1) the range between the upper and lower thresholds for the stimulus dimensions—the greater the range the higher the capacity and (2) the number of absolute judgments possible for the human to make along a stimulus dimension; e.g., while the human eye can identify reliably only five different brightness levels, as many as 13 different colors can be identified. The use of multidimensional coding technique enhances channel capacities significantly. Data from various studies of channel capacities for the senses are summarized below for unidimensional and multidimensional stimuli, respectively:

Channel Capacity (amount of information)—Unidimensional Stimuli

- Vision: 2.2-3.25 bits
- Audition: 2.3-2.5 bits

Channel Capacity—Multidimensional Stimuli

- Size + Brightness + Hue: 4.1 bits
- Position of Points in an Area: 4.6 bits
- Loudness + Pitch: 3.1 bits
- Frequency + intensity + interrupt rate + on-time fraction + total duration + spatial location: 7.2 bits

INFORMATION TRANSMISSION RATES

As in the case of sensory channel capacities the upper limit of human information transmission rate cannot be specified by a single value. The rate varies from task to task. Examples of transmission rates for tasks which have been studied are given below:

Information Transmission Rate

- Reading: 30-43 bits/sec
- Mental Addition: 23 bits/sec
- Typing Random Letters: 16 bits/sec
- Pointing to Targets: 15 bits/sec
- Choice Reaction: 6 bits/sec
- Choice Reaction—Spatially Patterned: 12 bits/sec

Human information processing capacity is a function of various conditions, some of which are listed here:

Information Processing Capacity

Function of:

Nature of Process

- Encoding—receipt of single stimulus and representation in memory
- Multiple-input—receipt of complex set of stimuli
- Transformation
  - Conservation (identification, one-one mapping)
  - Classification (condensation, many-few mapping)
  - Creation (problem solving, few-many mapping)
  - Compression (symbol reduction)
- Rehearsal (maintenance of stimuli in memory)
- Response selection/programming

Compatibility of processes

Single channel processing vs parallel processing

Other Factors:

- Number of Stimulus Alternatives and Knowledge of relative probabilities
- Stimulus-Response Compatibility
- Temporal Uncertainty
- Practice
- Sensory Mode (e.g., vision, audition, touch, smell)

DECISION MAKING

Human capabilities in complex decision making tasks may be comparable or, perhaps, superior to human pattern recognition abilities. The capability for drawing upon vast amounts of experience, including visual imagery stored in memory, if it could be automated, would require vast amounts of machine capacity in itself. Quantification in terms of information metrics is not available. Related qualitative principles for comparing man and machine functions are presented in Section II.

CONCLUSION

While human information processing functions have been quantified by communication theory metrics in several instances, extrapolation to operational tasks and situations is tentative at best. Systematic investigations to improve the capability for generalizing from human performance theory and related data to man-machine system design are currently in progress. Moreover, it is critical to note that while the metric may be the same, i.e., bits of information, there are difficulties in comparing human information capacities with those typically cited for machines. For example, two "messages" comprising the alternatives in a simple human choice reaction task are quantified as a single bit when calculating the information processing rate. Hence, the resultant measure of human performance neglects a significant amount of information processing involved in the neuromuscular process whereby the stimulus is sensed; decision rules are stored, recalled and applied; and a response is selected, "programmed," and executed—all of which would have to be accounted for in specifying the machine capacity required to fully automate the function.

SECTION II

PRINCIPLES OF MAN/COMPUTER DESIGN

MAN-COMPUTER INFORMATION PROCESSING CAPABILITIES

Section II incorporates two subsections dealing with man/computer relationships and computer decision aiding techniques; no attempt is made to specify specific design considerations for SDM—only implications can be inferred.

Following is a listing of human information processing capabilities and limitations published in a Honeywell document (12297-FR) entitled, *Information Processing Framework for Man/Computer Interaction: A Research Study*, which defines current state-of-the-art research issues.

- Man has extensive heuristic information-processing capabilities which cannot be duplicated by machine: he is able to apply creative solutions to unique problems and to eliminate large numbers of alternatives during the solution process (i.e., man is adaptable). The computer can be used to search and retrieve information based on man's direction and guidance. Due to its great speed of calculation, the computer can be an aid even when trial and error may be the only way to proceed. An example would be where the computer searches and retrieves from intelligence data files information on enemy threat capability (number of infantry troops, tanks, armor and artillery and their reported locations). A commander would evaluate these threat data in light of weather conditions and various hypotheses about potential enemy attack maneuvers and infer appropriate defensive action.

- Man's problem-solving process appears to contain a random element which enables him to attempt solutions which may not be a direct result of standard rule-following procedures; he is able to innovate and, thus, may arrive at unpredictable but successful, results. The computer could be used as a partner in this "ideation" activity, by recording man's output and providing a medium for generating novel relationships. An operator may elect a different course of action based on emergency or exigent information and deviate from a standard operational sequence. In case of an RPV control situation, a new unanticipated SAM or AA threat may be detected, necessitating a navigational route change. The computer allows the operator to initiate a navigational patch for which a new course is computed and command-linked to the RPV.

- Man requires a certain minimum amount of time in which to consolidate his thoughts (i.e., perform complex processing); this time is required primarily for the transfer of information between short- and long-term memory stores and for associating the information with the task at hand. A man/computer system organized on the principle of memory-to-memory communication should increase the efficiency of this consolidation and association process. Although a computer has orders of magnitude faster memory to memory transfer speeds (139 megabits/sec. for an IBM 370-155 as compared to 15 bits/second for human short term to long term memory), this advantage is made at the penalty of sizeable encoding time (time devoted to code development and programming). The human encodes information much more rapidly than the computer and has the advantage of random access coding. For example, a forward observer can make discriminations of friendly/target areas and associated terrain features for directing a strike in seconds or minutes which would require hours of programming to enter into computer storage.

- Man uses definable strategies in his information-processing activities; these strategies vary in their rationality and effectiveness; man's strategies may reflect some basic cognitive style which is characteristic of an individual's approach to a problem regardless of task specifics; some strategies, however, are modifiable by training or performance aids. In a computer-based system where such idiosyncracies form part of the data base, different cognitive styles would not necessarily limit or handicap performance. The less efficient strategies appear to place a greater strain on human memory, and this could be alleviated by computer-aiding. Humans differ in their cognitive style and value structure. Some commanders, for example, may be high-risk, high-payoff in their strategies where they may be willing to risk lives and equipment to maximize the probability for military gain, whereas other commanders may adapt a low-risk low gain strategy. Subtle differences in these two strategy approaches could be modified by defining objective utility functions to the computer in order for the commander to modify his strategies in either direction.

- Man's performance appears to suffer when he is required to perform several tasks in parallel, especially when the tasks are in different stages of completion. The computer's capability for storage would be an asset in this regard, for the system could actually switch from tasks in various stages of solution as either relevant data were received by the system or human "insight" occurred.

- Man is limited in his sensory and cognitive ability to deal with incoming information, unless the pattern is regular and predictable; man has difficulty in dealing with multiple sensory inputs. This is an example where an interactive system could buffer the information (i.e., hold it in queue) until man could process the information. The system could thus compensate for the tendency of man to deal with information overload by selective attention.

- Man has a finite channel capacity which limits the amount of information in a stimulus configuration that he can deal with effectively; as task stimulus complexity increases, performance is degraded; relevant redundancy can help alleviate this difficulty; however, irrelevant task redundancy has a disproportionate interference factor. Given the appropriate guidelines, many of these types of problems could be eliminated by preprocessing the stimulus inputs. The effects of various levels of this approach on system performance and efficiency are not known at present.

- Man requires fairly complete information on his performance to maintain or increase his effectiveness; his own expectancies can exert a powerful influence when feedback is periodic during critical periods of skill acquisition; man progresses from a requirement for general knowledge of results to a need for specific task feedback. A system dedicated to interactive information processing could be programmed to adjust feedback requirements relative to the level of performance and his location in the task sequence (i.e., incorporate principles of computer-aided instruction).

- The more deterministic the task environment, the simpler the task situation for man; however, man can effectively deal with complex probabilistic environments better than can a computer alone. The optimum approach to complex, unbounded problems appears to be man/computer synergism.

- Some relationships are more difficult for man to deal with than others (e.g., conjunctive problems versus problems based on disjunctive rules). In theory no such differences should be present when man is interacting with a computer to solve such problems, because the limitations due to human memory could be reduced.

- Most human beings are very susceptible to the influence of set or orientation generated by problem pattern, either structural or temporal; this rigidity can be evoked by relatively few occurrences of particular events; the effect is reduced by forgetting, thus suggesting the locus of the problem is in memory, probably short-term store. The capability of the computer to monitor behavior patterns would be useful in developing rules for alerting the operator (i.e., "breaking set", which is another area for study).

- Man appears in many diagnostic situations to be a conservative information processor in that he does not use all of the information available in input data and accordingly tends to acquire more data than he either needs or can use prior to some terminal behavior. Computer aids have been proposed and implemented to reduce this human propensity by allocating to a machine those tasks in which the man is more likely to display this tendency.

- Man's ability to formulate novel relationships is reflected in the fact that he is an effective information processor despite his cognitive limitations; this relates to his ability to develop heuristics for information reduction and conservation. The role of the computer in this regard would be as a vehicle for depicting these relationships and for performing the analysis necessary for evaluation and verification.

- Man has been found to be more responsive to a criterion of accuracy than timeliness when both are system parameters. The computer has the capability to operate in non-real time (i.e., "fast time"), thereby providing the human operator the capability to evaluate many more alternative courses of action within limited time constraints without sacrificing his search for accuracy.

- Humans in decision situations tend to delay their action selection inappropriately; this is especially prevalent when the man is at a relative disadvantage. Again computer-aiding is a reasonable mechanism for channeling the operator's thought processes and overcoming this tendency toward inertia in problem solving and decision making.

- Man has a nearly limitless capacity for variety in his behavior; this is reflected in his unique capacity for innovation, originality, and creativity; man has a special capability in the idea-generation aspect of problem solving. The computer can enhance this process, but it can by no means duplicate it.

- Man is acknowledged to be a superior pattern recognizer especially when the patterns are both temporal and figural in content. Further, the interpretation of patterns, such as voice communication, relies upon man's ability to contribute his own experiences to the interpretation. Thus, for the present, man's role in this regard cannot be duplicated by machine but can be enhanced by providing variable displays capable of controlling pattern changes.

PRINCIPLES OF MAN/COMPUTER DECISION AIDING

Although the previous section enumerated some qualitative principles of man/computer functional allocations with some supporting examples, little in the way of quantitative design trade-off functions are provided. One area of man/computer technology that does have some quantitative research data to establish some quantitative trade-off criteria is computer-aided decision making.

Advances in computer technology during the past twenty years have impacted all phases of human endeavor. Many functions which were once considered uniquely human are now performed faster and with greater accuracy by sophisticated machines. In complex military systems this revolution has been reflected in a variety of ways: (1) Better sensors have increased the amount and fidelity of data input. (2) The resultant data is processed rapidly by advanced computers. (3) Commanders are provided with increased variety, mobility and effectiveness in weapon systems and, (4) Advanced communication systems facilitate rapid integration and application of available military resources. However, at the decision-making level, man is still largely on his own. Moreover, technology advances have increased the amount of information to be evaluated while decreasing the amount of time available for doing so.

The question concerning how machine capabilities might be adapted to aid the human in the decision-making process has been addressed by a series of command-control simulation investigation conducted at the Ohio State University (OSU) Research Foundation under sponsorship of the Aerospace Medical Research Laboratory during the 1960's (Howell, 1967). Those studies deal primarily with the diagnostic functions, whereby present environmental states are assessed and future states predicted.

Analyses of decision making behavior identified several processes basic to the diagnostic process. Perhaps, most critical among them is the judgment of how likely to exist, or occur, are the various possible states of the environment. For example, what are the relative probabilities of (1) enemy attack, (2) enemy feint, or (3) enemy withdrawal in a given situation? Such judgments may be made at two points in time: before (t_1) and after (t_2) collection of some amount, or a specified set, of diagnostic data (D). When the two judgments are expressed in probability terms, the first, or "prior", estimate is symbolized as P(H); the second, or "posterior", estimate, as P(H/D). (P refers to *probability* and H to the hypothesis with regard to the environmental state). Thus, the diagnostic process may become a succession of probability estimates with regard to critical states of the environment as data, or information, is collected. The diagnostic process ends with the incorporation of all available data into a terminal P(H/D) estimate upon which a decision is based.

However, in making the critical posterior estimates, the diagnostic system must judge the predictive value of each data set collected in order to make an appropriate adjustment in the prior estimate. The process whereby the adjustment is made may take place as follows. Suppose that previous information indicates that P(H) for attack by the enemy is high, but recent satellite sensed photographic data (D) indicate a reduction of troop concentrations in the area of concern. Now, to come up with a revised P(H/D), an estimate must be made of the likelihood that the observed reduction of troops would occur in conjunction with each possible state of the environment which might result, e.g., attack, feint and withdrawal. Each of the latter estimates is usually symbolized by P(D/H), i.e., the probability of the observed data given the particular hypothesis. The P(D/H) estimates made by the diagnostician may be based on how frequently he has observed D when each H actually occurred, or on some other more subjective basis. It may be more natural to think of judging the *odds* that a particular D would occur for H_1 rather than H_2, e.g., 2 to 1, or 3 to 5, etc., rather than .50 or .60, etc., but the basic concept is the same.

A simple example will help clarify this model of diagnostic systems. Suppose that satellite surveillance data from a given geographical area is being collected for the purpose of determining which of two environmental states prevail: enemy force present (H_1) or enemy force absent (H_2). It is assumed that the initial position of the intelligence analyst is that the two hypotheses are equally probable of being correct. Hence, the prior $P(H_1) = P(H_2) = .50$. Now, the intelligence analyst learns through the satellite network that the last enemy attack occurred within 5 miles of the area of interest. He can now improve upon his prior estimate of .50 by taking this new information (D_1) into account. Suppose his past experience has been to observe enemy forces within the area of interest 80% of the time when an attack has occurred 5 miles away. Thus, $P(D_1/H_1) = .80$ and $P(D_1/H_2) = .20$.

Now the new data can be incorporated into the prior estimate by a technique known as Bayes Theorem which involves the multiplication of $P(D/H)$ by $P(H)$ in the following manner. $P(H_1)$, .50, is multiplied by .80 to obtain .40. $P(H_2)$, .50, is multiplied by .20 to obtain .10. These new values are proportional to the *posterior* $P(H/D)$ estimates which the diagnostician wishes to determine. The ratio of the two new values is called the "likelihood ratio." The actual $P(H/D)$ estimates are obtained by normalizing both values so that they sum to 1.00.

Thus, $P(H_1/D_1) = \dfrac{.40}{.40 + .10} = .80$ and $P(H_2/D_1) = \dfrac{.10}{.40 + .10} = .20$

become the posterior estimates. This same procedure can be applied successively to update assessments of the state of the environment regardless of how many data are collected.

Although it is unlikely that one can find a current military system which actually implements Bayes Theorem, there is some evidence that experienced humans aggregate information in a roughly analogous manner. One purpose of the OSU research program was to determine how much diagnostic proficiency might be improved by automating the aggregation function.

A condensed summary of major findings from the OSU research program is presented in Table 1. In addition, 13 principles were formulated on the basis of the research results. Some of the more salient of these are listed below.

- Automation of the aggregration process can improve the quality of decisions by 10-15 percent when diagnostic decisions are made under a wide variety of conditions.

- The advantage of automating data aggregration increases as the fidelity of input data declines. (Humans tend to concentrate on only the highest quality information and ignore data of relatively low predictive value).

- The advantage of automated over human aggregation of predictive information is maintained over a wide range of feedback levels as long as some feedback is provided.

- Increases in human stress factors, e.g., increases in workload and reductions in time available to do the work increase the advantage of automated aggregation.

- Humans tend to make conservative probability estimates when performing without automated aiding.

Within the context of satellite data management system planning and design, the foregoing comparison of automated versus human diagnostic processes appears to have implications for the development and use of data compression techniques consistent with user needs and capabilities. Elaboration upon such implications is beyond the scope of the present study effort. However, quantitative definition of data compression requirements by virtue of using Bayesian computer-aiding techniques could only be achieved through a real-time operator-in-the-loop simulation effort where communications network and data processing and compression parameters are experimentally controlled.

TABLE 1

SUMMARY OF OVERALL COMPARISONS BETWEEN HUMAN AND AUTOMATED AGGREGATION EFFECTIVENESS

Experiment	Range of Conditions Studied	Average Decision Scores* Human	Automated
22A	Experience: 114 Hours-234 Hours	47	54
22B	Fidelity (Input): Complete-Medium	56	55
23	Fidelity: Medium-Low Time Stress: 1-7 Min./Decision	21	31
27	Automated Aggregation Aid: Present-Absent	25	45
28	Human Control Over Aggregation Aid: Low-High	74	74
8	Knowledge of Results: 0-100%	34	41
21	Payoff Functions: Linear, Log, All-Nothing Information Load: 4-12 Data Items Prior Uncertainty: High-Medium	62	70
19	Information Load: 4-12 Data Items Prior Uncertainty: High-Medium	69	80
18	Nonindependent Input Data: None-High	69	74
	Overall Averages:	45	58

* In most cases, the score refers to percent correct decisions averaged over the entire range of conditions.

SECTION III

ISSUES OF MAN-MACHINE DESIGN IN SDM

SOURCE-TO-USER INFORMATION PIPE

Section III relates the first two general sections to some of the anticipated conceptual design issues for Satellite Data Management—the associated diagrams and figures are proposed for use in program briefings (see Appendix).

There are two distinctly different ways of examining the satellite data management problem. The first is to examine the system from the sensor portion of the system while the second is to examine the system from the user terminal end of the system. Since the usefulness of the information depends upon how the user perceives and acts upon the information, the user is the driving element of the system. The size of the user pipe influences the entire system. Since the input/output stages of human information processing are slower than the central processing stage, i.e., human thought processes, the absorption and retransmission of the data will be the limiting factor. The primary standard to judge the success of the mission whether it be surveillance, message communication, threat evaluation, resource allocation, or whatever, is the success in having the appropriate action taken in a timely manner. This then leads to examining the critical nature of the information displayed, the accuracy required, the time stress associated with the information, and finally, the actions taken and the decisions made on the basis of the information. These relationships are depicted in Fig. 2. Some issues which derive from these relationships are listed below.

PIPELINE 1 FUNNEL ISSUES

- Man/Machine Transfer Metrics
  - Physics of Display   Psychophysics of Information
  - Connotative vs Denotative

- Man/Machine Synergistics
  - Net Output Exceeds Limiting Component
  - Man-Computer Synergistic Integration

INFORMATION STRUCTURE ISSUES

To emphasize the operator portion of the effort, the data management project can be displayed in a different format. Figure 3 displays the hardware associated parameters and the operator associated parameters separately. In each area there are limitations and uncertainties. If, in the final analysis, the operator cannot act correctly upon the presented information, there are different areas in the flow to the information source which must be changed. The FY 7T effort was addressed toward evaluating the state of the art in the operator information processing capacities and terminal design and display hardware parameters to provide the basic information for interaction into the source and network evaluations. Any future efforts must take into account all system areas listed below to insure that the proper feedback loops are examined.

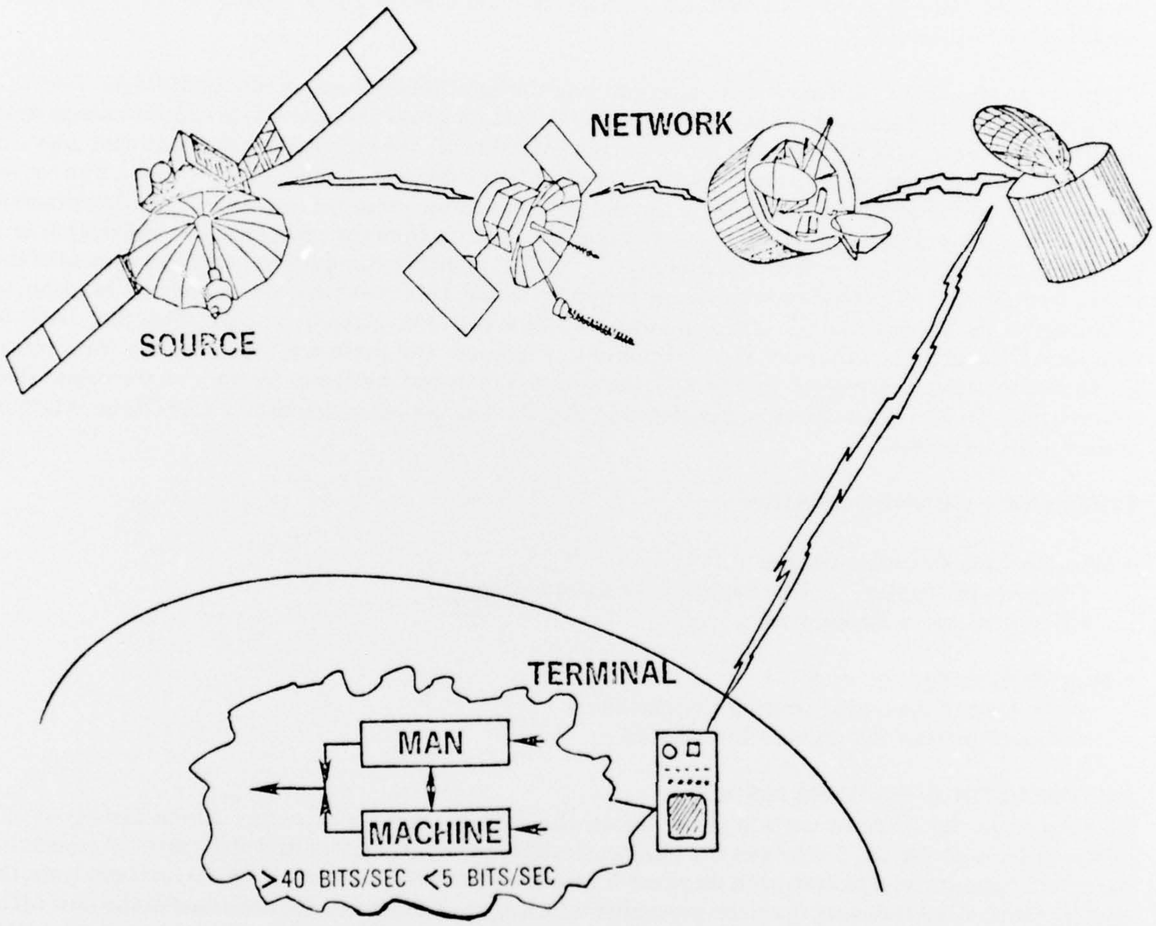

Figure 2. Mission Relationships

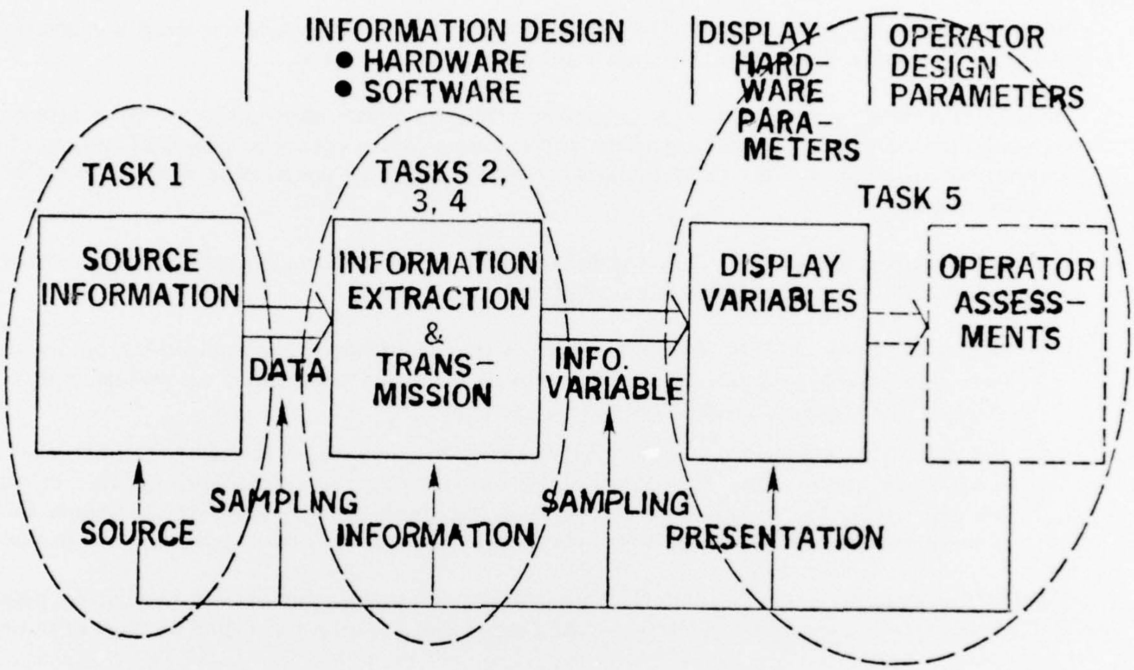

Figure 3. Hardware and Operator Associated Parameters

SDM INFORMATION STRUCTURE ISSUES

- User Requirements Dictate Feedback Loops
  - Data Sampling
  - Data Correlation
  - Data Compression

- Information by Exception
  - Tolerance Limits
  - Time Dependencies

BASIC MAN-MACHINE FUNCTIONS

Taking the user point of view, one can size the information rate requirement out from a terminal by examining the rate at which the user can assimulate the information. The rate can vary as a function of the type of information required. There are a limited number of functions which will be done by man or a machine or a combination of the two. Definition of SDM functions and Man-Machine functions are outlined below.

DEFINITION OF FUNCTIONS

SDM SYSTEM FUNCTIONS:

Surveillance — systematic observation of aerospace, surface, or subsurface areas, places, persons, or things by visual, aural, electronic, photographic, or other means.

Reconnaissance — a mission undertaken to obtain, by visual observation or other detection methods, information about the activities and resources of an enemy or potential enemy; or to secure data concerning the metereological, hydrographic, or geographic characteristic of a particular area.

Communications network — (JCS, IADB) An organization of stations capable of intercommunications but not necessarily on the same channel.

communications — (JCS, IADB) A method or means of conveying information of any kind from one person or place to another, except by direct unassisted conversation or correspondence through nonmilitary postal agencies.

communications satellite — (JCS, NATO) An orbiting vehicle, which relays signals between communications stations. They are of 2 types: (a) Active Communications Satellite—A satellite which receives, regenerates, and retransmits signals between stations; (b) Passive Communications Satellite—A satellite which reflects communications signals between stations.

Threat Assessment — evaluation of the importance, size and significance of an existing, potentially hostile, or enemy, force and/or associated expressions of intent to inflict damage or injury.

Allocation — (JCS) The designation of specific numbers and types of aircraft sorties for use during a specified time period or for carrying out an assigned task.

Allocation (Nuclear) — (JCS) The apportionment of specific numbers and types of nuclear weapons to a commander for a slated time period as a planning factor for use in the development of war plans. (Additional authority is required for the actual deployment of allocated weapons to locations desired by the commander to support his war plans. Expenditures of these weapons are not authorized until released by proper authority).

MAN-MACHINE FUNCTIONS:

Attending — activating and adjusting sensors in order to maximize the probability of registering environmental stimuli.

Filtering — eliminating or rejecting unwanted stimulus information.

Detecting — discovering or determining the presence of stimuli, data or events.

Preprocessing — encoding stimulus information to facilitate storage, gross classification and condensation.

Storing — placing and preserving information in a store place, e.g., memory.

Processing — transforming, collating and combining information including inductive/deductive processes, and decision making derived from the application of criteria.

Transmitting — sending and presenting information including the use of displays and control devices.

INFORMATION FLOW FOR MAN-MACHINE FUNCTIONS

Using specific functional areas, one can illustrate tentatively projected data rates in an example. Figure 4 illustrates an example of a surveillance mission giving the human input/output data rates associated with the man-machine interaction for given functions. The time flow is indicated by the arrows. It is assumed that the satellite data management system has information stored in it when the user initiates the initial request. When decisions are made, one switches from the right-hand column to the left-hand column. The estimated data rates in bits/sec that can be absorbed by the operator are the numbers in parentheses. The code for the degree of operator involvement is located in the left-hand corner of the functional blocks. High operator involvement is indicated by a plus (+), low operator involvement by a (−), and medium operator involvement by (=). Since the input-output functions of memory, execute, classification and communication action can be either operator or hardware limited they are coded high and medium operator involvement. The critical point to note is that the user information pipe is very small. This limitation influences the actual distribution system itself all the way back to the information source.

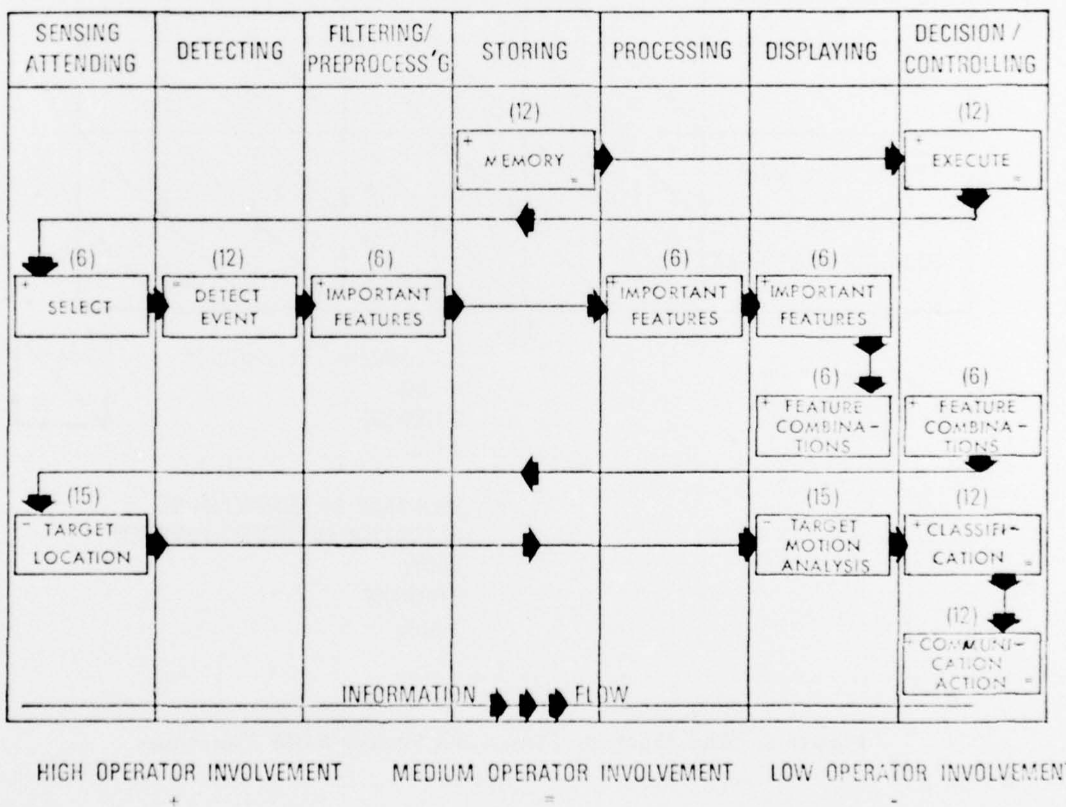

Figure 4. Information Flow for Man-Machine Functions

MAN-MACHINE FUNCTIONS VS SDM FUNCTIONS

The man-machine functions can be evaluated in terms of the system data management system functions as illustrated in Figure 5. The primary areas of interest are those items where the state of the art is low but the relevancy of the man-machine parameters to system functions are high. These would be 1/3 and 2/3 blocks, respectively; concentration of follow-on effort in areas represented by the 1/3 blocks should be given priority since it will have a major impact on the network architecture. Having discussed the operator capabilities, in general, and SDM man-machine system function in particular, let us turn to some specific control-display design parameters.

SDM SYSTEM FUNCTIONS	SENSING/ ATTENDING	DETECTING	FILTERING/ PREPROCESSING	STORING	PROCESSING	DISPLAYING	CONTROLLING
SURVEILLANCE/RECCE	3/3	3/3	2/3	2/3	2/2	2/3	1/1
COMNET	2/3	1/2	1/3	1/3	1/3	1/2	1/1
THREAT ASSESSMENT	1/1	1/1	1/3	1/3	2/3	1/3	1/2
RESOURCE ALLOCATION	2/2	1/2	1/2	1/3	1/3	1/3	2/3

SOA - STATE-OF-ART IN MAN-MACHINE TECHNOLOGY
1-LOW
2-MEDIUM
3-HIGH

SOA/R

R - RELEVANCY OF MAN/MACHINE PARAMETER TO SYSTEM FUNCTION
1-LOW
2-MEDIUM
3-HIGH

Figure 5. Man-Machine Functions Versus SDM Functions

COMPUTER CONTROL/DISPLAY TERMINAL DESIGN FACTORS

Interactive alphanumeric and graphic displays, usually CRT type, with various types of keyboards and light guns have become common interfaces between human operators and advanced computer-based data systems. Some related control/display design considerations are summarized below:

CRT DISPLAY DESIGN FACTORS

- Flicker

  Phosphor type (e.g., p1, p11, p20, p28, p31)

  Refresh rate (e.g., 50 Hertz)

  Update rate (e.g., 2 × natural freq. of displayed info or 2 × operator response rate)

  Luminance/Contrast (e.g., $\frac{LB - LF}{LF} = .50$)

- Image Quality

  Resolution (lines/inch)

  Grain Size (e.g., grain size < 20 sec. arc)

  Jitter (e.g., < ½ stroke width)

  Brightness (e.g., not less than 10 ft. lamberts, 100 ft. lamberts for high ambient lighting conditions. Ambient illumination shall not contribute more than 25% of screen brightness through diffuse reflection and phosphor excitation)

  Edge gradient sharpness or acutance (not less than 2)

- Multi-purpose vs Dedicated Display Areas

KEYBOARD DESIGN FACTORS

Resistance (e.g., 26 g-150g pressure)

Displacement (e.g., .8mm-4.8mm)

Size/Separation (10-19 mm and 6.4 mm)

Functional Layout/grouping (sequential use; logical flow, etc.)

Multifunction vs Dedicated Switches

Identification

Orientation (15-25° slope) and Height (between elbow and shoulder)

DATA INPUT/MODIFICATION MODES

- Keyboard/Track Ball-Cursor/Light Pen

  Speed

  Precision

INFORMATION ENCODING

Considerable attention has been given to determining appropriate methods of encoding information for effective transmission via such terminals. Criteria for selecting appropriate methods have been derived from the data summarized in Section I of this report.

- Alphanumerics

  Numbers and letters are the most common method for presenting information. This method facilitates the use of standard typewriter keyboards for data entry. However, extensive use of alphanumerics may cause the display to become too cluttered for effective use in some applications.

- Geometric Forms

  The use of geometric forms, or shapes, as symbols can effectively alleviate the cluttering which results from the display of lengthy texts, or legends, comprised of alphanumerics. A single geometric symbol may convey a large amount of information.

  Geometric symbols used to encode information range from simple dots to complex polygons and include straight line segments of different lengths and widths, arcs, angles, etc. However, symbols should be selected so as to maximize associative value and discriminability. It is also recommended that the number of different geometric symbols used within a coding system be held to a maximum of 15 if possible.

- Size

  When symbol size is used as a coding dimension, it is recommended that no more than 5 different sizes be used, preferably 2 or 3.

- Brightness

  Two to four levels of brightness have been found to be effective for encoding information on displays.

- Flashing Elements

  Flashing a display element is an effective way of attracting attention. The optimum flash rate is 2 to 3 cycles per second.

- Color

  Color also can be effectively used to reduce display clutter and facilitate information transmission. It is recommended that no more than 11 different colors be used for such purpose within the same systems; six is the maximum for rapid, error-free transmission. The fact that many people are totally, or partially, color blind is the principal disadvantage of color coding.

The foregoing actually represents only a sample of man-machine considerations related to the terminal interface design. More complete coverage can be found in a number of human engineering design publications. In addition, the interrelationships between design of the terminal interface and factors identified in preceding sections of this report must be evaluated at all stages of system design.

The composition and design of man-computer terminal interfaces are closely related to the system purpose and software provisions for information flow between man and machine. An analysis of these interrelationships has been made by Martin (1973). In non-real-time systems printouts of information may be provided to the user periodically. Real-time systems usually differ in that the user communicates directly with the computer in a two-way dialogue to obtain or enter data. There are many different ways of implementing man-computer dialogues, e.g., dialogue with programming-type statements, menu-selection dialogues, graphics with chart displays and symbol manipulation provisions, dialogues with photographic presentations, English language dialogues, etc.

When a method, or methods, of data information exchange has been selected, hardware requirements must be established. An important consideration at this point is the response time required, i.e., the time the user must spend waiting for a reply from the machine. Ideally, this delay should be as short as possible; 5 or 10 seconds can seem like a long time when the user is anxiously waiting to proceed with an important task. However, trade-offs may have to be made between costs for fast response and the criticality of time delays to system or mission objectives.

Response time is related not only to the amount of data, number and complexity of operations, and computer capacity, but also to display capabilities at terminals. For example, typewriter-like terminals respond at a rate of 6-15 characters per second, which may be too slow for efficient dialogue in some mission contexts. A display connected to a telephone line may present as many as 600 characters per second. Graphics terminals, although they typically require greater bandwidth channels than alphanumeric displays, usually permit high rates of man-computer interactions. Figure 6, derived from Martin (1973), shows relationships between data rates (bits/sec) and generality of use for several types of terminals.

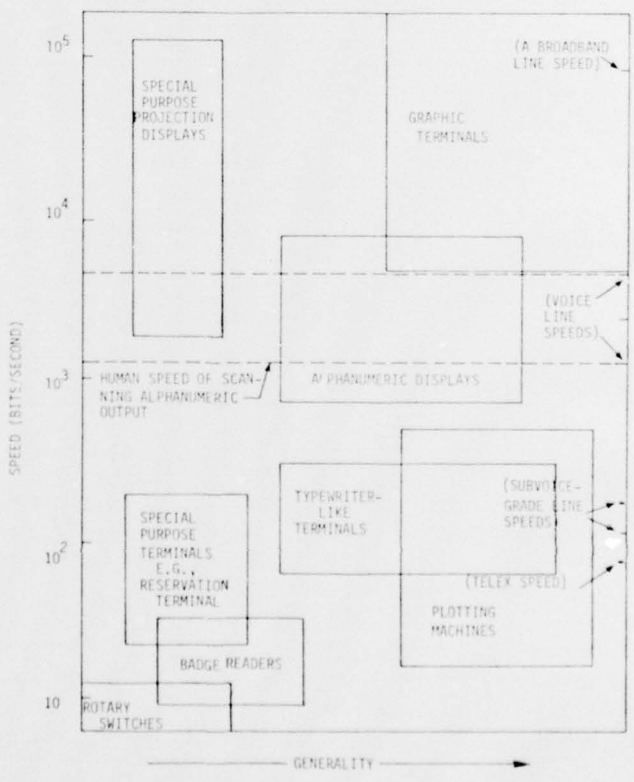

Figure 6. Typical Terminals: Speed and Generality of Use

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